California Coastal Sea Level and Wind Wave Variations During the Historical Record

Peter D. Bromirski
Reinhard E. Flick, Daniel R. Cayan, Nicholas Graham
Scripps Institution of Oceanography

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COASTAL IMPACTS

- Sea cliff retreat and beach erosion
- Inundation of lowlands and coastal wetlands
- Storm surge related flooding
- Saltwater intrusion into estuaries and freshwater aquifers

Most of the damage caused by sea level variability occurs during episodes of

Extreme Sea Levels and Extreme Wave Heights

Public Facilities At Risk

California Coastal Records Project (x4)

Sea Level Variability

- Tides (global mean sea level rise)
- Long period SLH variability and El Nino related steric changes
- Storms: includes wind-forced surge as well as the inverse barometer effect caused by sea level pressure changes
- Waves (not included in the tide gauge record)

Sea Level Height Variability

- Time Scales:

  Daily, Synoptic, Monthly, Seasonal, Decadal

- Tide Dominant (predictable)

- Focus: Storm-Forced “Surge” Variability

GLOBAL SEA LEVEL RISE

- Steric (thermal expansion from warming of the world’s oceans)

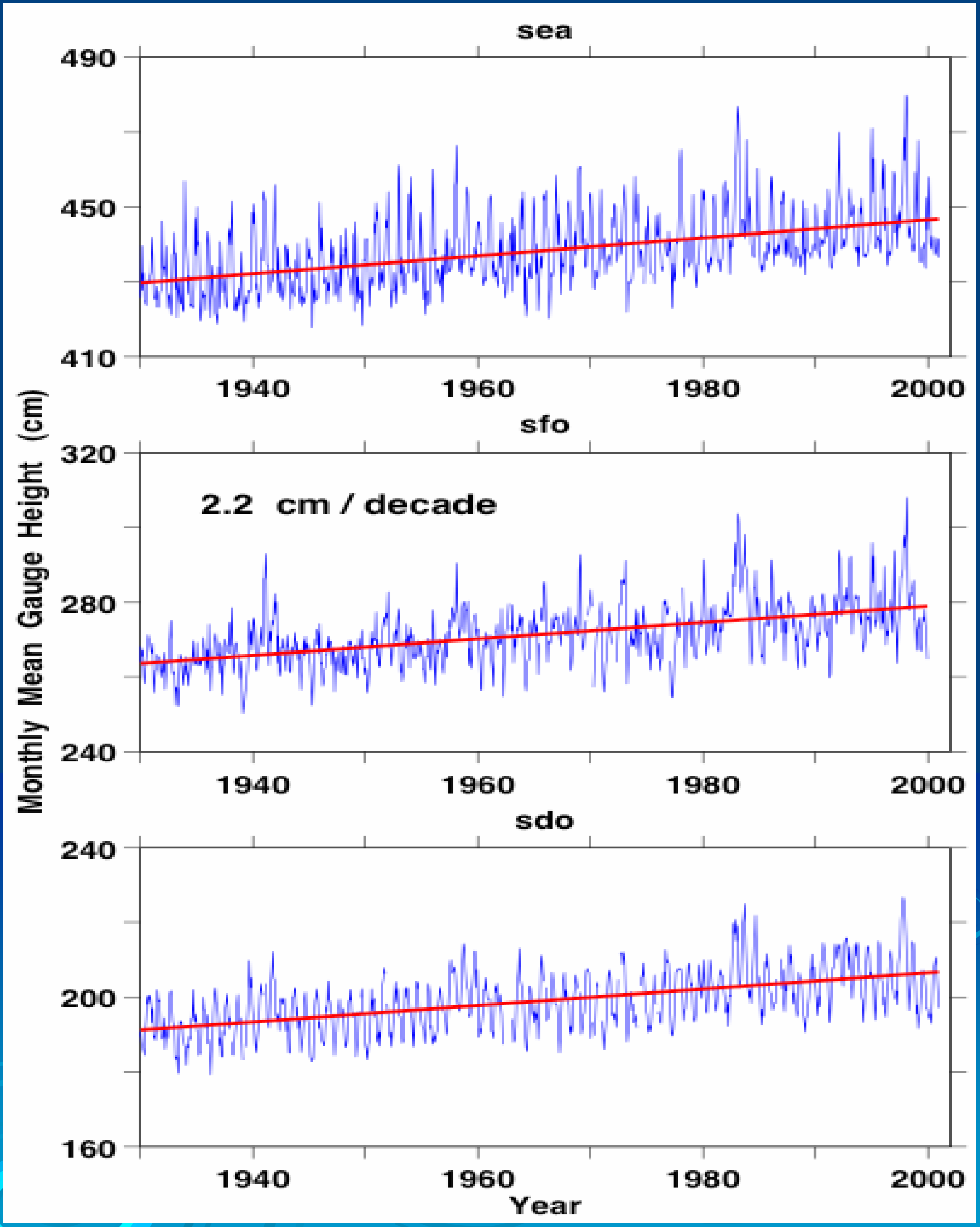
- Eustatic (added water from melting glaciers and ice caps)

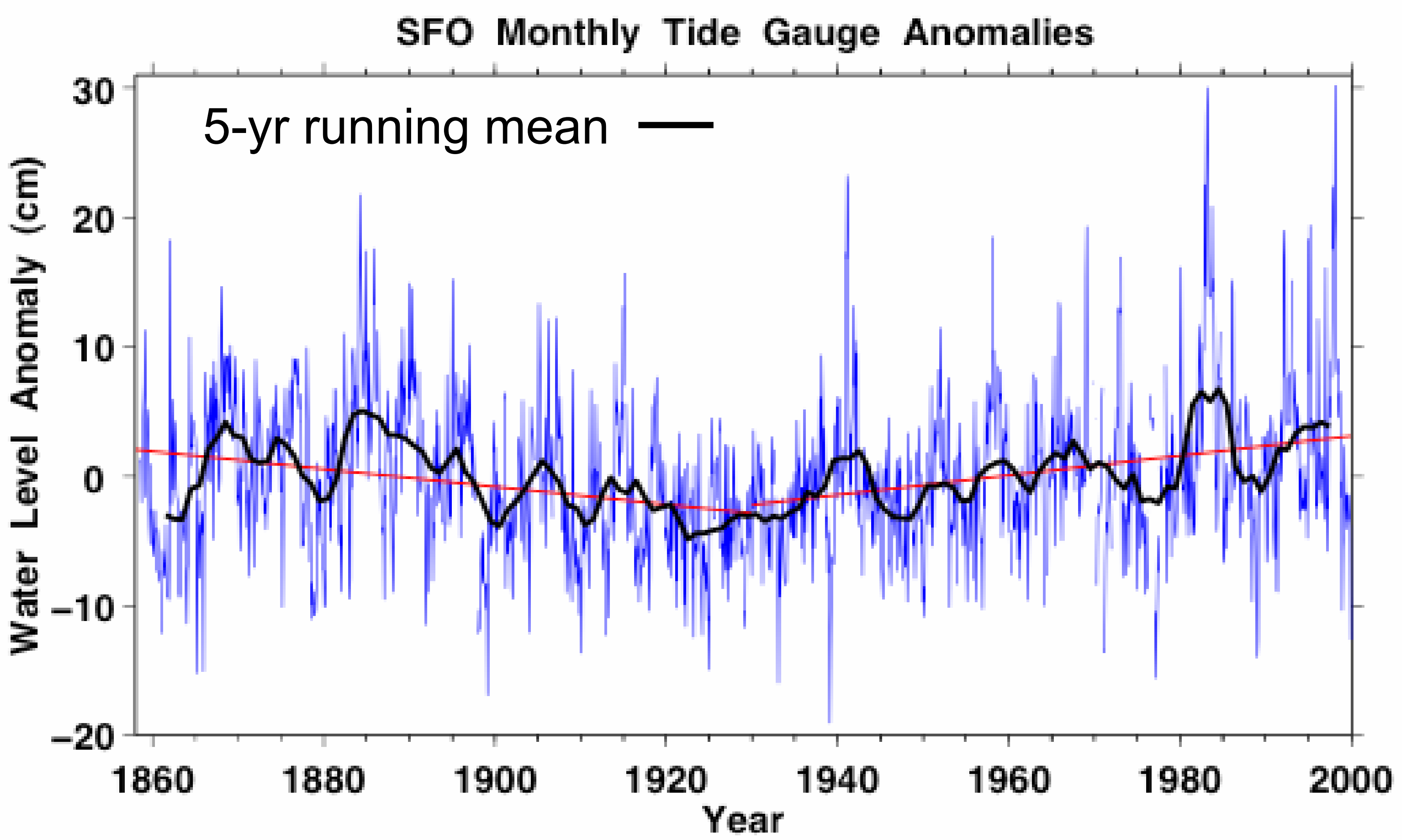
Mean sea level rise: ~ 20 cm / century

Well established trends in sea level rise along the West Coast

Long period variability most prominent at San Francisco (SFO)

Increases tend to persist for several years





Decadal-scale variability in SLH is much greater than long-term trends over the same time period

Meteorologically-forced Non - Tide Water Levels

To study storm-forced variability requires removal of the dominant astronomical tide signal

Frequency domain operations to remove tidal energy

Removes long period changes in Sea Level & most El Nino related Steric increases

The resulting time series gives a measure of “storminess”variability

(Bromirski, Flick, & Cayan, J. Clim., 2002)

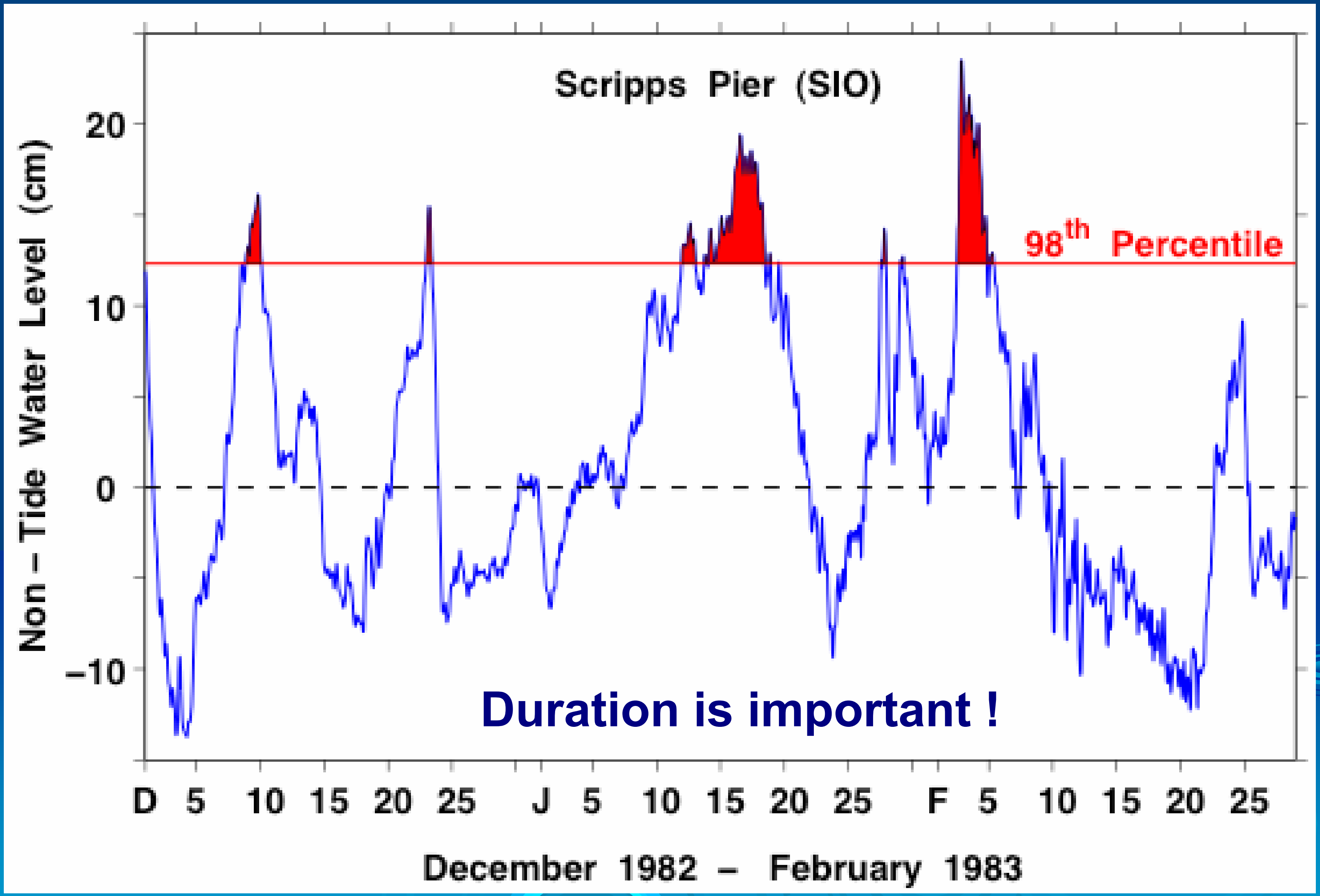
Storm - Forced Extremes

• Storm-forced variability occurs on synoptic time scales of 2-6 days

• Extremes are characterized by cumulative sums of Non-Tide amplitudes exceeding the 98th percentile of all positive Non-Tide realizations,   i.e. the top 2%.

• Long period variability is determined using winter (November - March) cumumlative extremes.

Extreme Non-Tide Levels



GREATEST COASTAL IMPACTS

"High" High-Tide

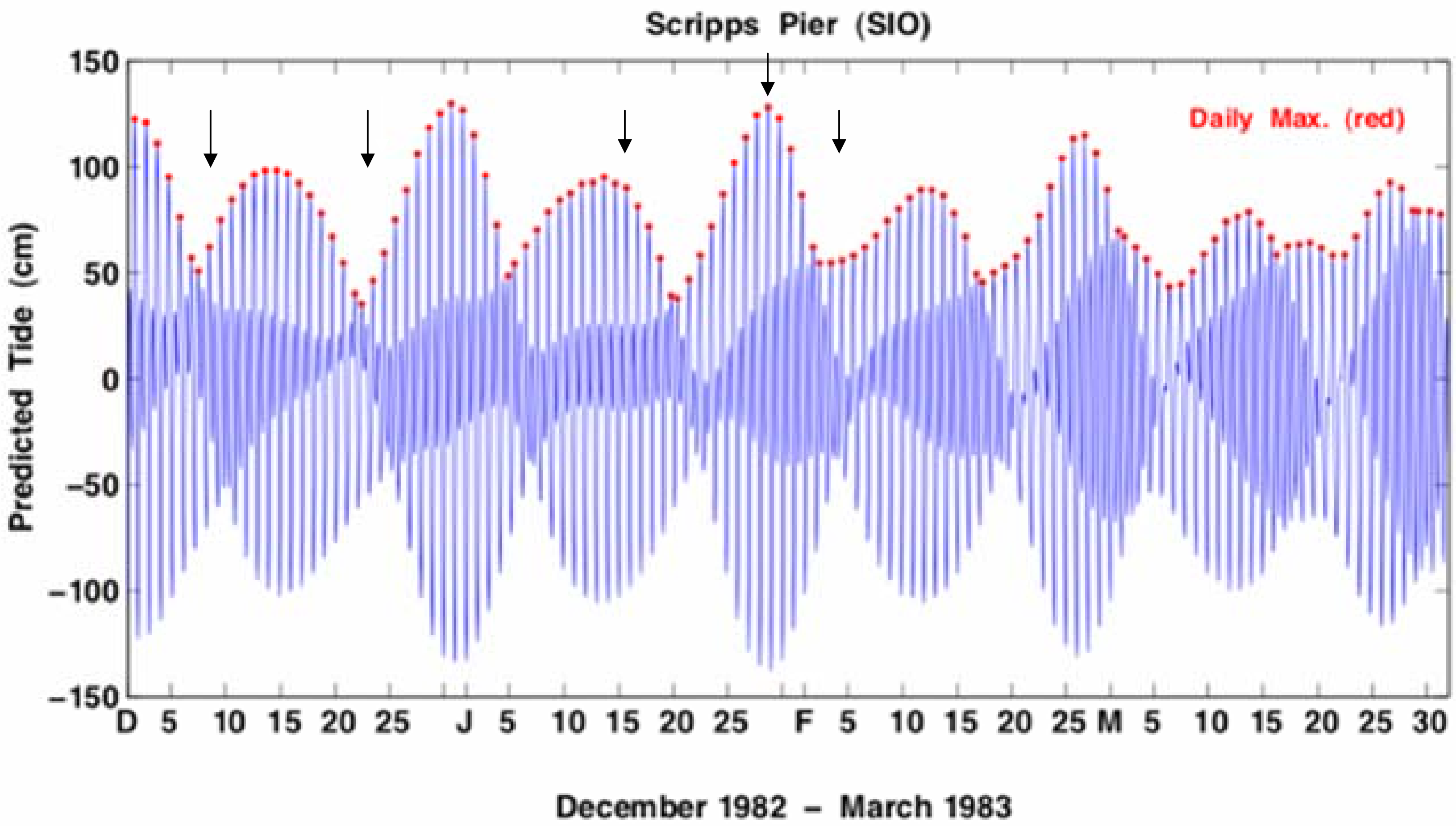
in conjunction with

Extreme Storm - Forced Sea Levels

Extreme Surge + Extreme Waves during High Tide

Successive storms remove buffering beach sands, enhancing impacts

High Tide Variability



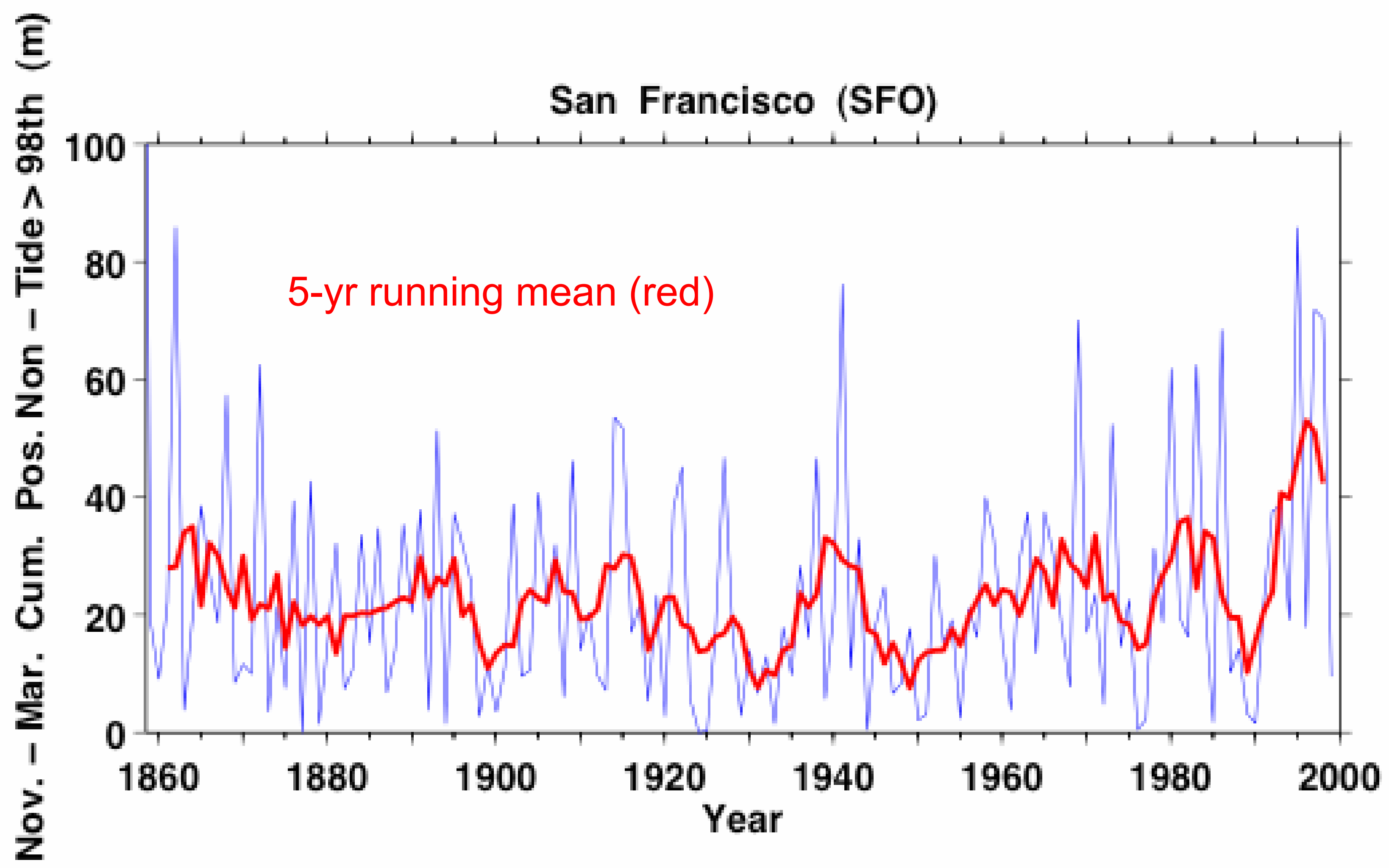
High tide levels vary by about 1 m

Highest storm-forced level = 28 cm

Ocean Beach , February 1983

Effect of Extreme storm-forced sea levels during an extreme tide

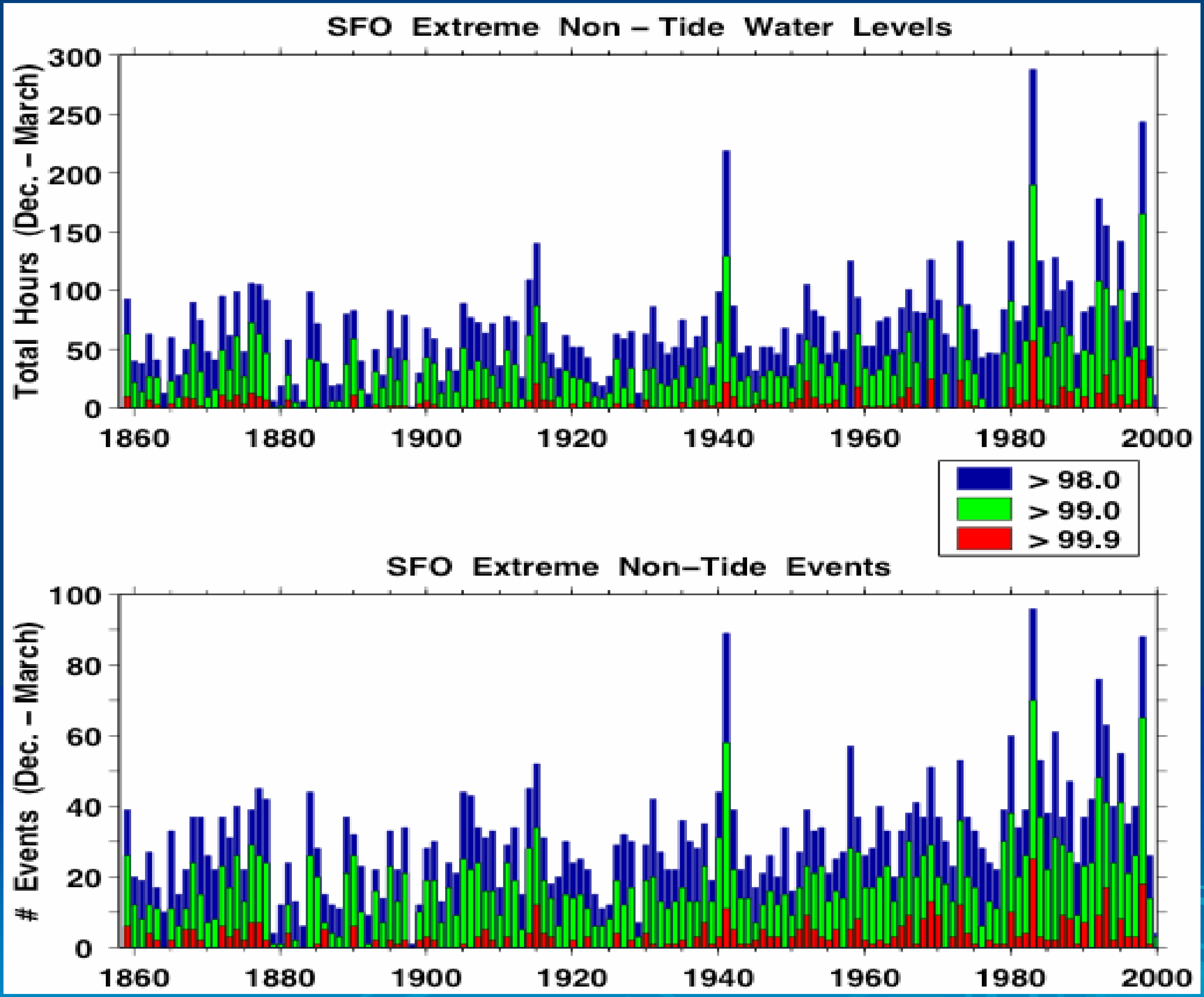
Winter Storm-forced Variability



Highest levels observed in the 1990's

Upward trend over the last 50 years

Storm - Forced Sea Levels



Increasing frequency and duration of extremes

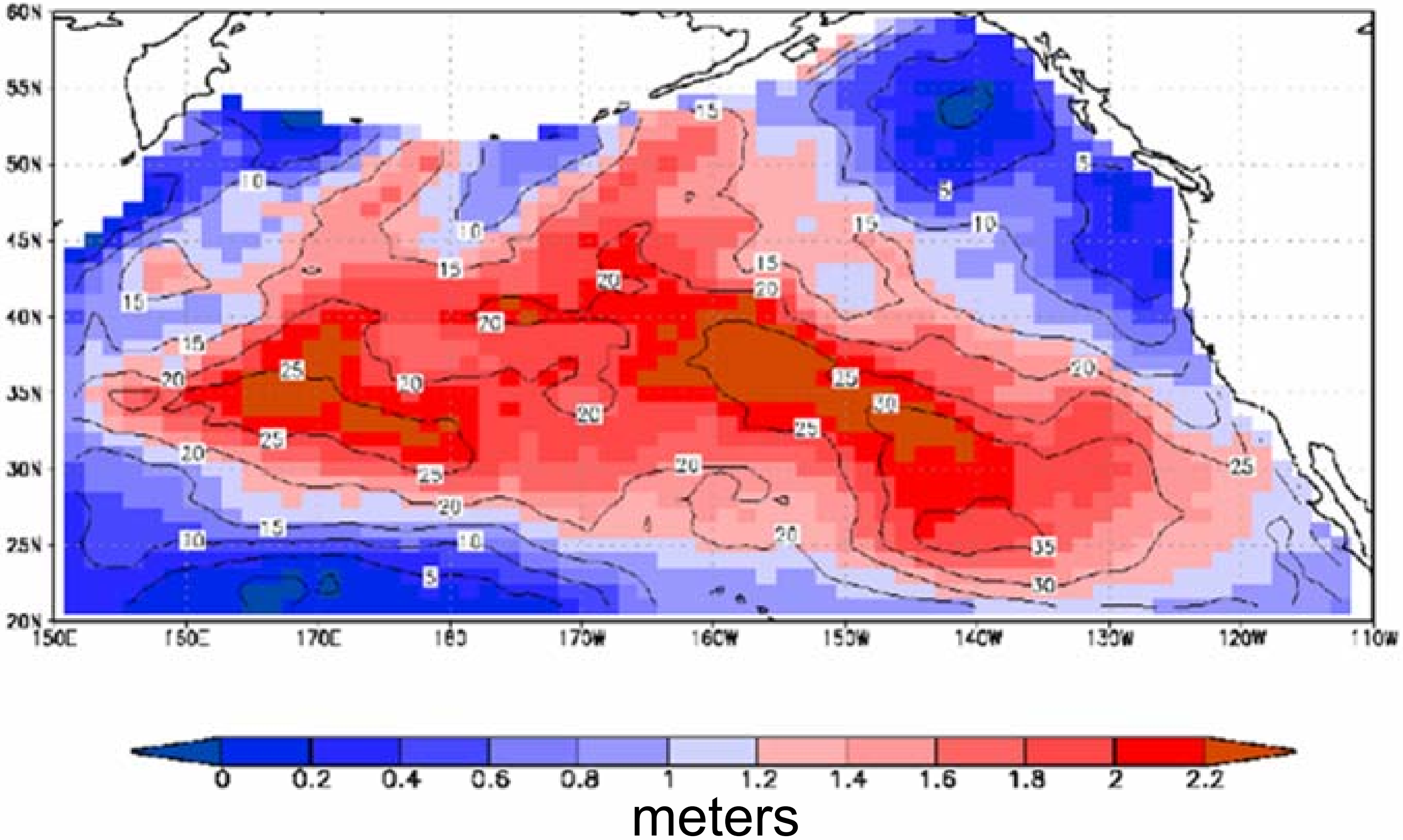
WAVE CLIMATE VARIABILITY

- Wave model hindcasts: 1948 - 1998
  (Nick Graham)

- NOAA Buoy data: 1981 - 2003

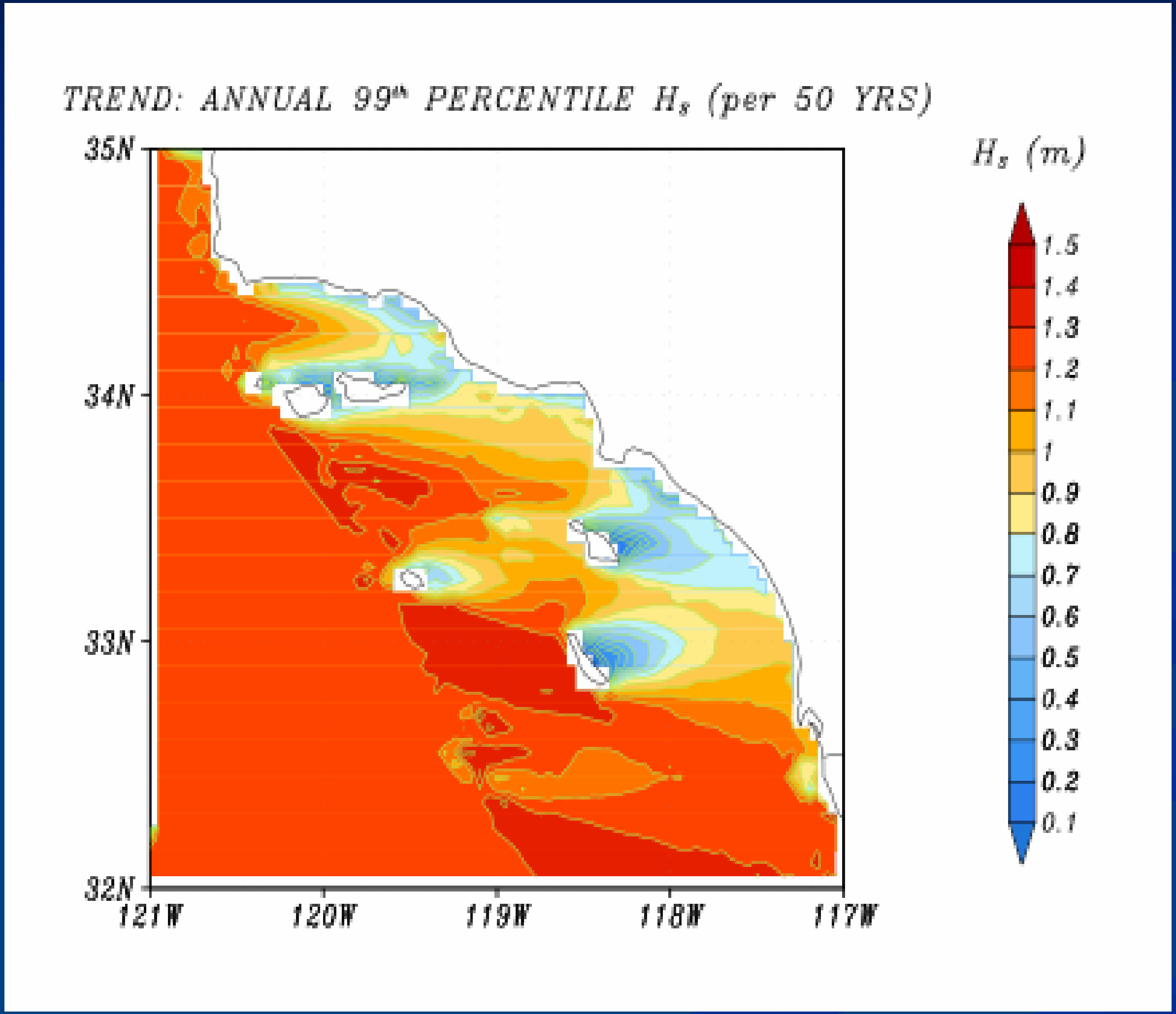
Extremes of significant wave height
(Hs , the average of the highest 1/3 of the waves)

Upward Trends in Extreme Wave Height



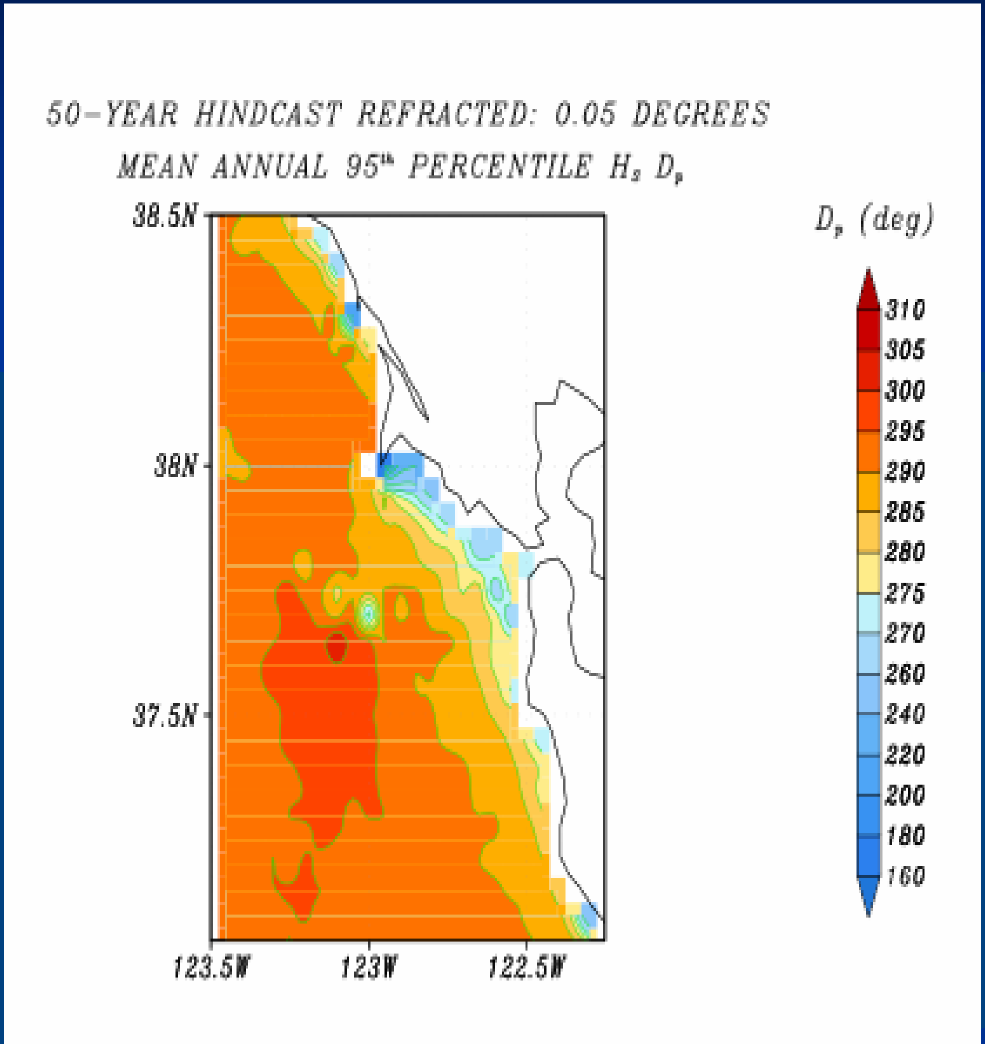
(Contours are % of mean 99th percentile Hs)

Upward trend in wave heights



Wave angle is important !

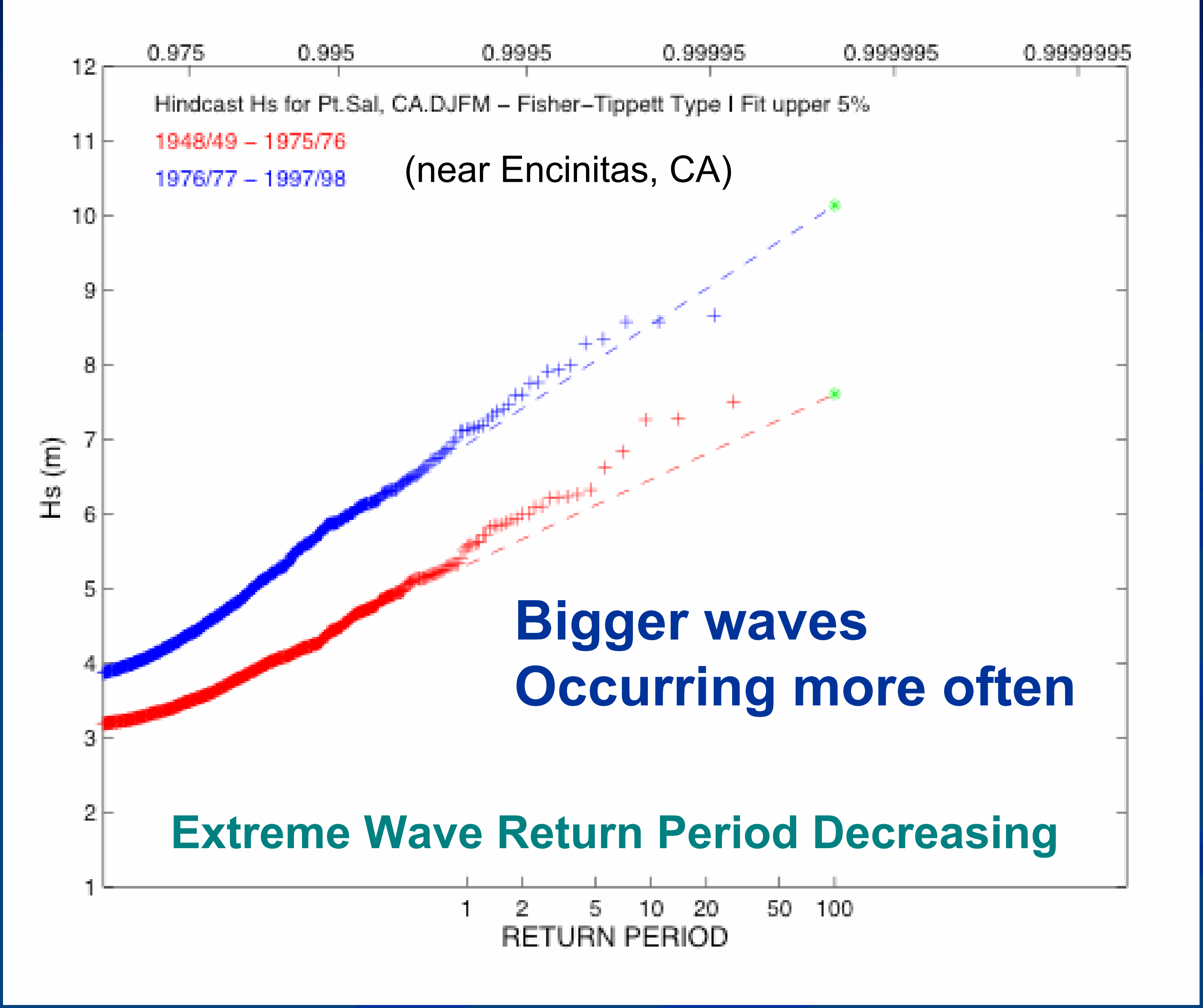
Extreme Wave Direction



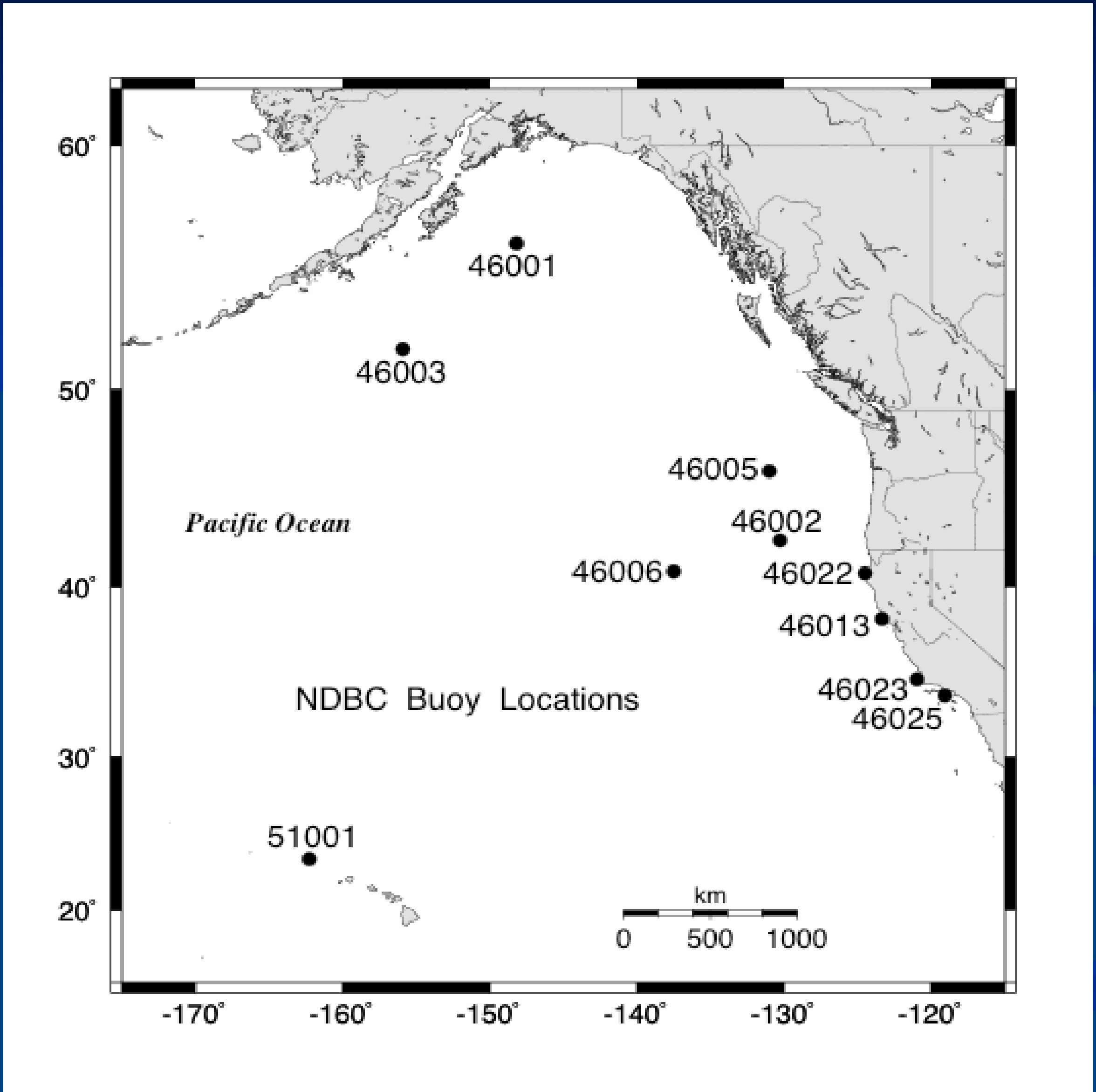
More Southerly Direction at coastal locations

Areas sheltered from the north more often exposed to wave energy from the south

Increasing Wave Height since 1977

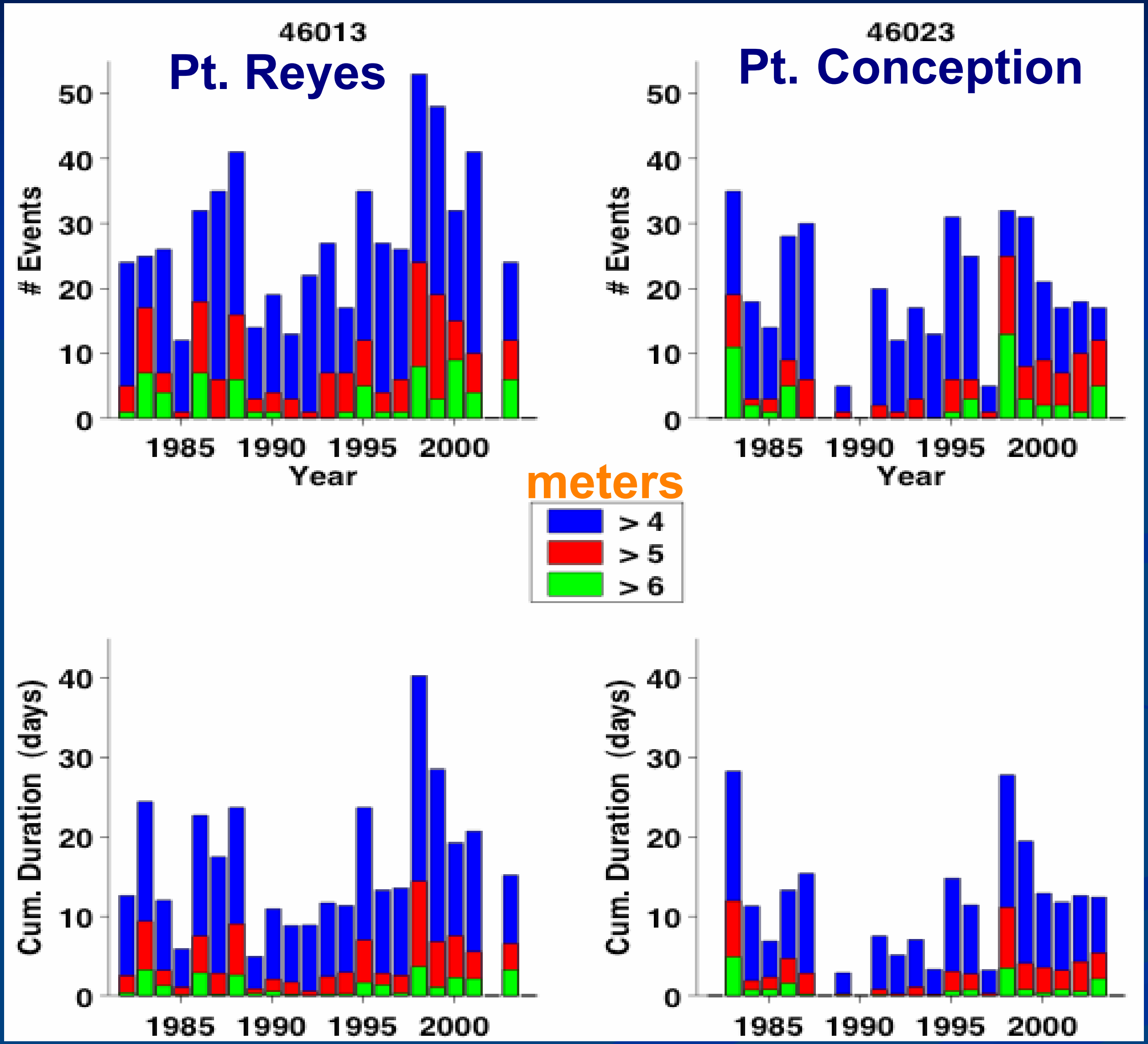


NOAA Buoys



60˚
50˚
40˚
30˚
20˚
-170˚
-160˚
-150˚
-140˚
-130˚
-120˚
46001
46003
46005
46002
46006
46022
46013
46023
46025
51001
Pacific Ocean
NDBC Buoy Locations
km
0
500
1000

Extreme Wave Heights (Hs)



Higher waves during the 1997-98 El Nino and late 1990's than during the 1982-83 El Nino

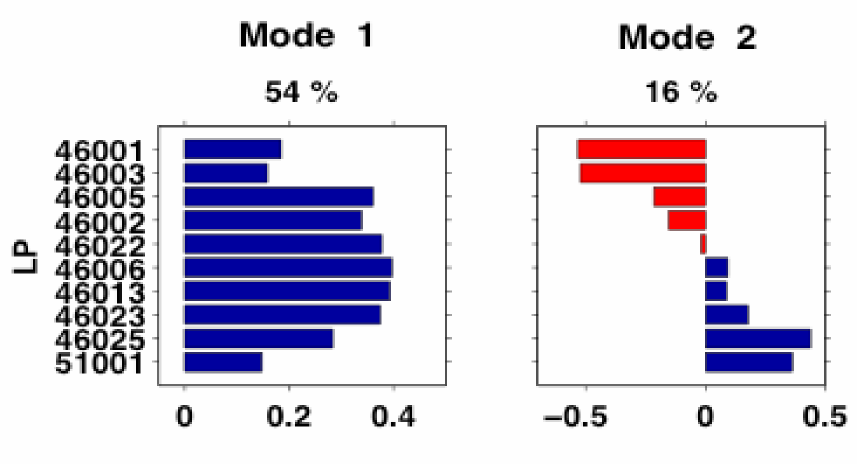
More northerly storm tracks during 1997-98 El Nino

More extreme events causing longer duration of extremes

Implication: storm intensity is increasing

WAVE SPECTRA

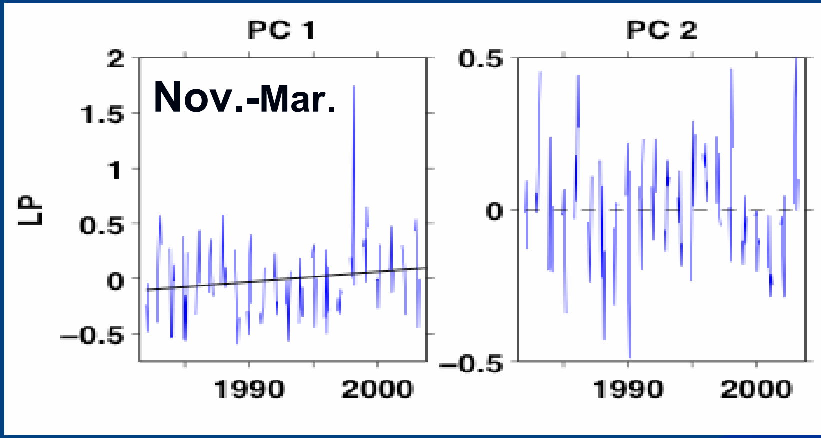
EOFs



Long period (LP) wave energy (T > 12s) is generated only by large, very intense storms

Variability of LP energy gives a measure of "storminess" in the Northeast Pacific

Principal Components



Significant upward trend for PC1 implies increasing storm intensity

IMPACTS

Development Creates Sand Shortage Crises

Solana Beach

Extreme Sea Cliff Erosion

Fort Ord, south central Monterey Bay

Conclusions

- Mean sea level, storm frequency and intensity, extreme wave height: ALL have UPWARD trends.

- TIMING is critical !!!

  The occurrence of "high" high tides concurrently with extreme storm-forced sea levels magnifies coastal impacts.

  Increasing storm frequency increases the probability that this will occur, as well as the increased impact from closely-spaced successive storms.

  Concurrent extreme waves further enhance the coastal impact.

- The upward trend in mean sea level will increase the impact of extreme waves and storm surge, allowing more wave energy to reach sea cliffs and lowlands.